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THE SOLAR FLARES OF AUGUST 28 AND 30, 1966*

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Abstract. We describe observations of the class 3+ flare of August 28, 1966, made at the Mount Wilson Observatory. This great proton flare followed the sequence: (1) Precursor flare; (2) Filament eruption; (3) Beginning in penumbra of large spot; (4) Rapid elongation in two strands; (5) Great spray and surface wave; (6) Rapid separation of two strands to maximum brightness; and (7) Slow spread of brightness and decay.

The soft X-ray burst coincides with stages 3–6, decaying through stage 7; the hard (> 80 keV) burst coincides, but decays more rapidly.

Considering a demi-cylinder of emitting material, the soft X-rays are explained by a 4-million-degree plasma, or at least a large flux of electrons with that amount of energy. Given this flux, the microwave burst is explained by synchrotron emission with the low frequency cut-off due to coronal absorption.

The class-2 flare of August 30, 1966, is also discussed.

1. Introduction

Large-scale cinematograms obtained at Mount Wilson permit us to make a detailed study of the development of the great proton flare of August 28, 1966. Aside from the good quality of our observations, complete X-ray (hard and soft) and radio data obtained at various observatories (and kindly communicated to us) make possible a comprehensive study of this event. In particular, correlation of the X-ray and radio bursts with the flash phase of the flare permits us to evaluate the extent of the hot component responsible for these emissions. In our study, we cannot escape the impression that the 'great flare', of which this is an example, is qualitatively different from lesser flares.

Films of the event were obtained by Lawrence S. Anderson with the Mount Wilson 150-ft. tower. A reduced-size image, 175 mm diameter was photographed at 10-second intervals through a Halle filter; the image was stabilized by a photoelectric guider. The typically good early morning seeing rapidly deteriorated during the flare as the sun rose in the sky; but the frames of the early stages resolve some features as small as 1 arc sec.

Hyder (1968) has published some prints from our 16 mm reduction prints, and some discussion of the flare. In this paper we try to present the detailed Mount Wilson observations, and comparison with non-optical data.

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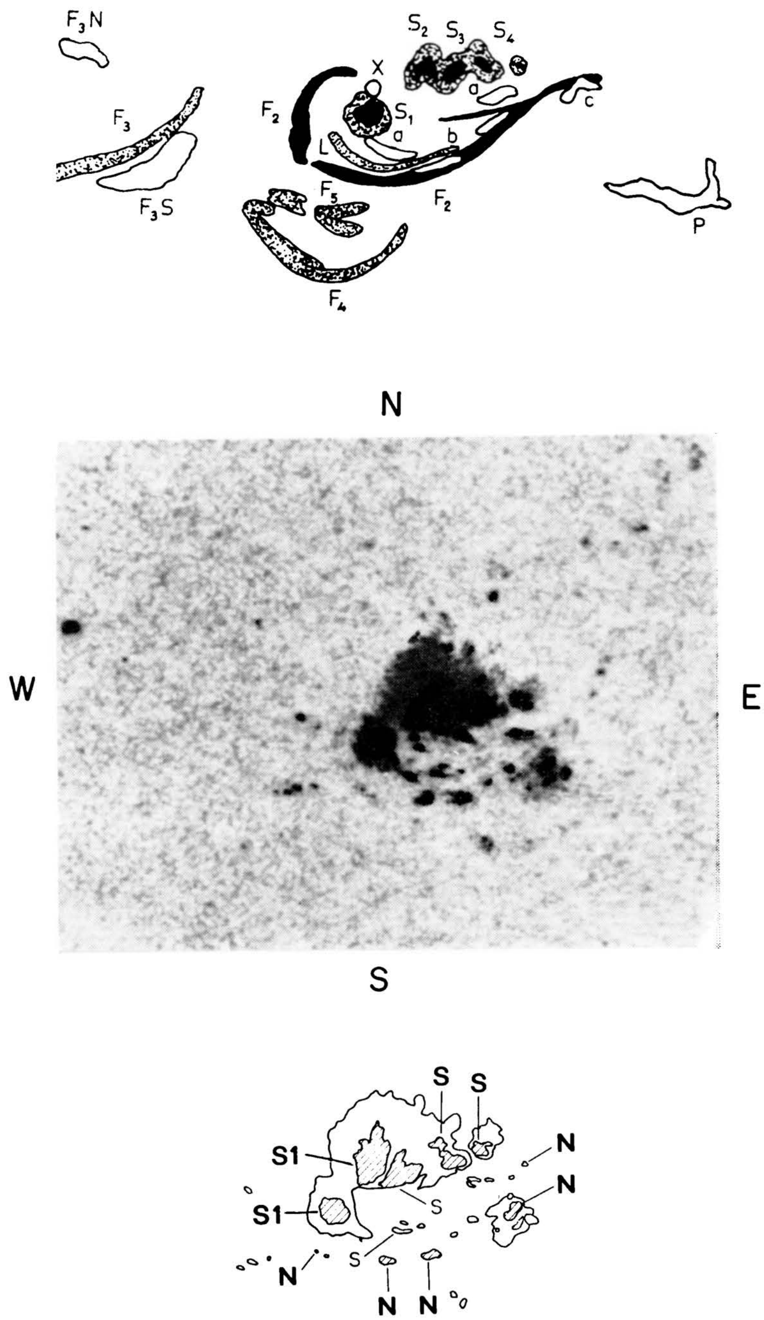
The sunspot group associated with the McMath plage No. 8461 was preceded by a scattering of spots connected with plage No. 8459, which DODSON and HEDEMAN (1968) note played an important role in the flare development. In Figure 1 we show magnetic polarity data as well as a white-light photograph kindly communicated by



(a)

(b)

(c)

Fig. 1. (a) Finder diagram of the more important features in the August 28, 1966, flare area. $S1, S2, S3, S4$ constitute the row of sunspots as visible in Hα. The dark lanes are upper-level filaments. The dotted lanes are lower-level filaments. The white areas are the bright points in development of the flare.

(b) White-light pictures of the spot group by ESSA, August 28, 1966. (Courtesy P. J. McIntosh.)

(c) Corresponding magnetic field polarities according to McIntosh (1967), derived from various sources.

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Mr. P. J. McIntosh. The spot group consisted of a large, complex group of umbrae in common penumbra, with a sharp line of polarity division along the South edge. To the South of this line are located two curving rows of small spots of N polarity. The main flare brightening occurred in two strands along these rows of small spots; there was little brightening over the big spots. The main flare, which began at 15.20.45 UT, was preceded by a precursor subflare at 14.51.00, the eruption of a small filament at 14.58.00, and a large one at 15.06.30.

McIntosh (1967) has remarked that there was considerable motion between the two preceding umbrae during the period of the flare. On the days following, the group evolved into a more typical configuration with a large complex following spot. We present photos of a class-2 flare on August 30 as well (Section 7).

To illustrate the discussion, we show (Figure 1a) a finder sketch for the Hα photographs. We see a sunspot-type filament, $F1$, arched over the active region, probably marking the line of zero vertical magnetic-field component. From the bright area at the West end of $F1$, a second filament, $F2$, loops into the heart of the spot group between $S1$ and $S2$, ending at point X, in the penumbra of $S1$. A dark structure, L, which may be a filament, but is more likely a dark lane in the plage, runs parallel to $F1$. The double-branched $F4$ marks a region where a precursor flare occurred (Figure 2b). Another filament, $F3$, associated with two bright regions at the West, appears at the top of Figure 1. These may not all be filaments; some may be chromospheric fibrils.

2. Precursor Activity

Table I summarized the chronology of the event. At 14.51.00, a small precursor flare occurred in the region delimited by $F1$, $F4$, and $F5$. The brightening began at the North-West end and then spread between the two filaments (Figure 2). Before the flare ended at 15.06.00, filament $F2$ blew off at 14.58.38. Brightening appeared for a few minutes between the two umbrae at X, at 15.17.45.

TABLE I

Time sequence in the August 28, 1966 event

14.51.00	Precursor flare (small microwave burst began 14.46.00, peak 14.51.00.
14.58.30	Small filament disappears.
15.06.30	Large filament $F1$ begins to rise (gone by 15.21.30).
15.18.00	Soft X-ray burst begins (OGO 3).
15.20.45	Small brightening at large spots.
15.21.15	Small brightening in preceding plage 8459.
15.22.00	Rapid elongation of flare. Start of radio burst.
15.24.51	Two strands begin to expand.
15.25.30	Beginning of hard X-ray burst (> 80 keV).
15.28.20	End of rapid expansion of strands.
15.29.00	Hard X-ray maximum.
15.31.00	Soft X-ray maximum.
15.33.00	Maximum Hα brightness and area.

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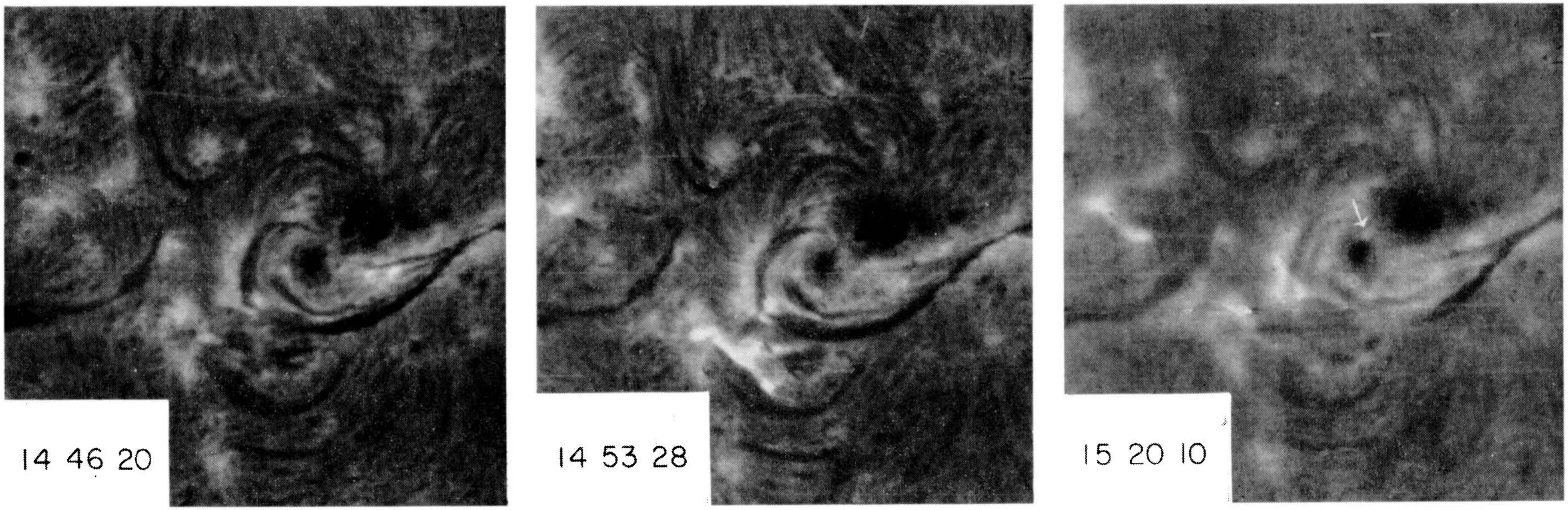

Fig. 2. (a) The flare area before activity began. (b) Precursor flare. (c) Brightening in the point X between two sunspots. Note filament F_1 in eruption, indicated by the arrow.

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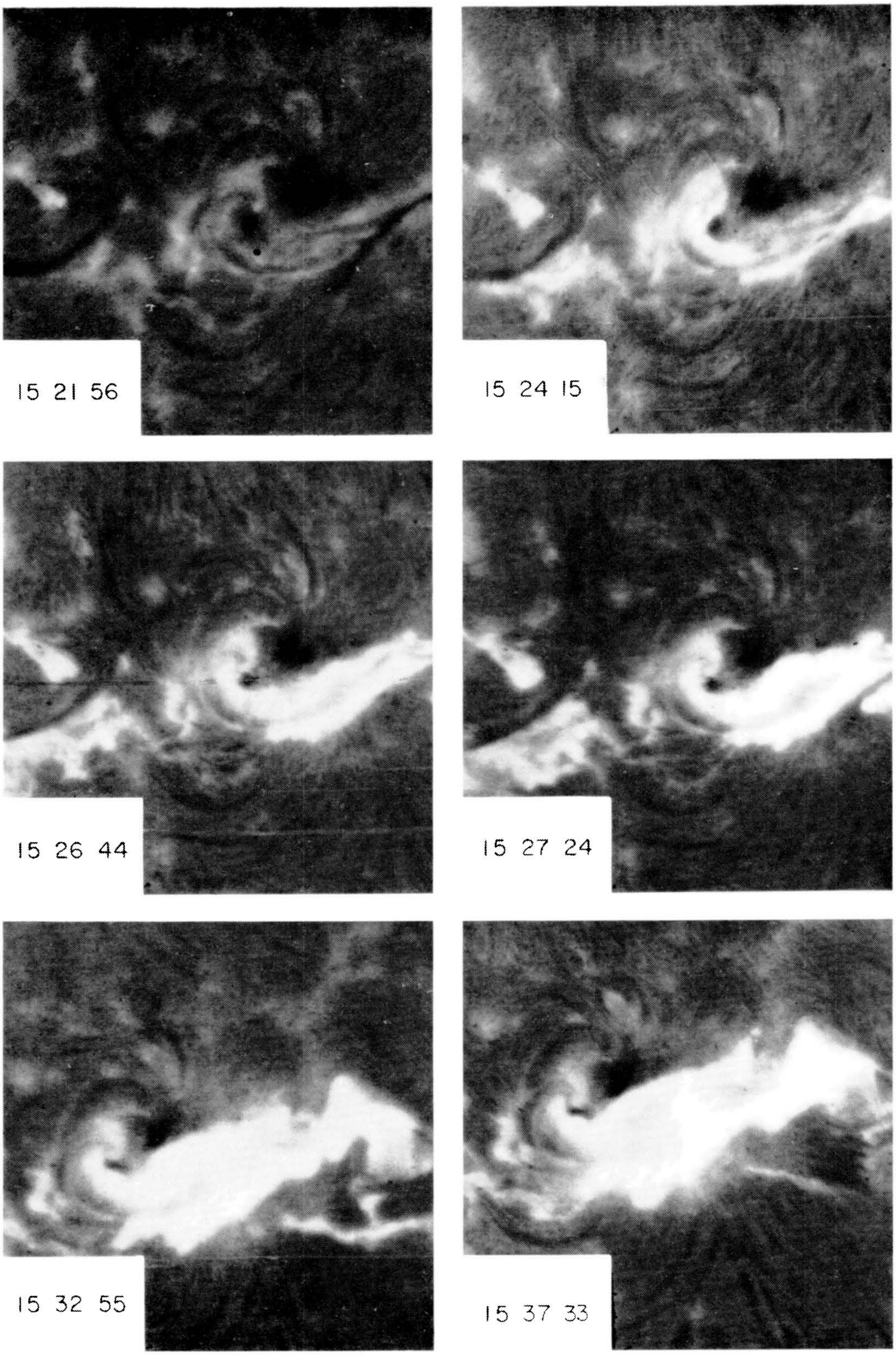

Fig. 3a.

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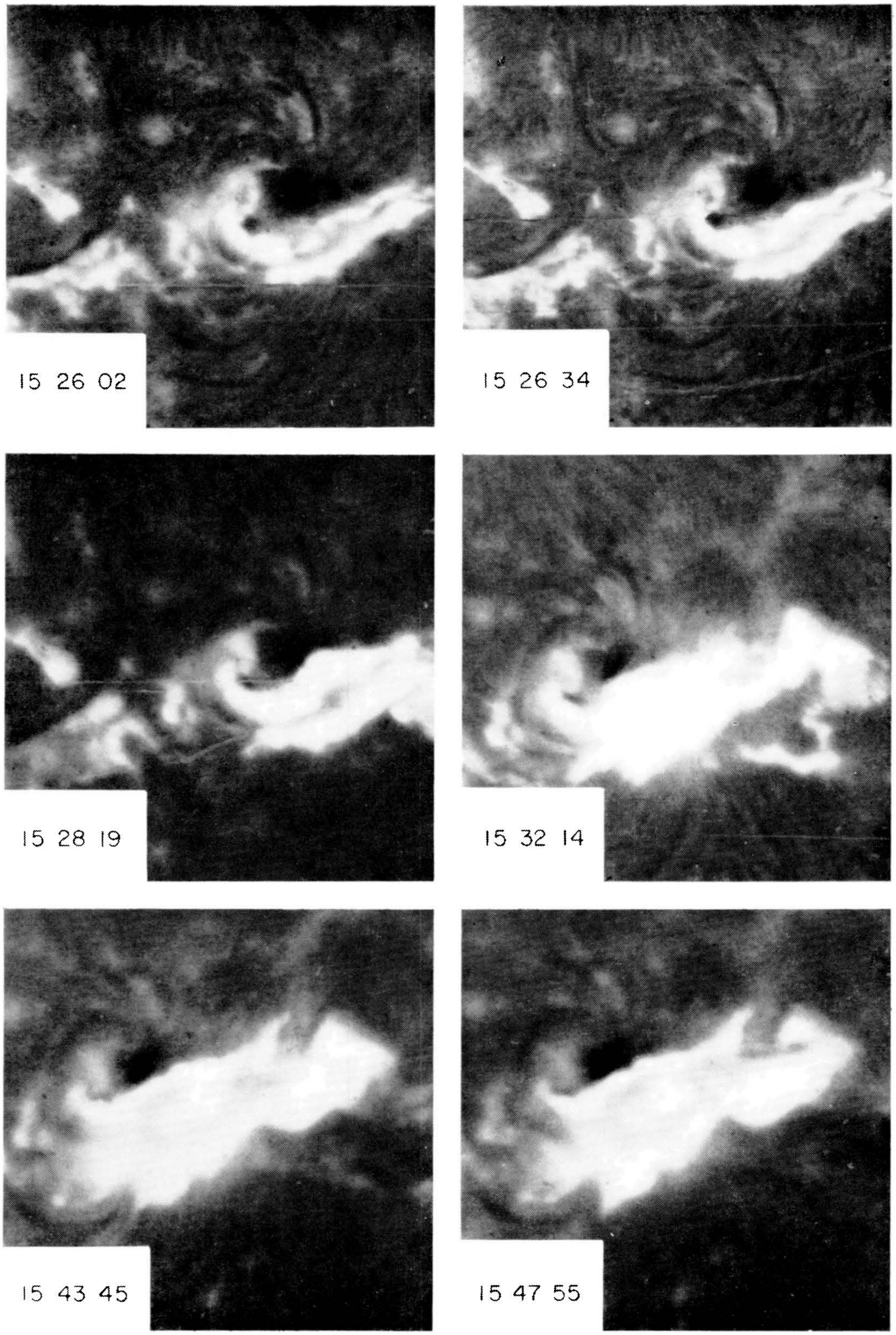

Fig. 3b.

Fig. 3. Sequence of the frames during the flare.

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The large filament, $F1$, began to rise at 15.06.30; most of it was gone by 15.21.30 (Figure 2c). The eruption of filament $F1$ is a typical preflare event, as has been shown by numerous observations at the Lockheed Solar Observatory (RAMSEY and SMITH, 1966). $F1$ broke in half, and erupted upward; presumably the top shifted to the violet out of our band pass (Figure 4). A small bright area North of filament $F3$ ($RF3$) was enhanced with the preflare and lasted longer; at 15.01.30, emission spread toward the nearby filament $F3$. At 15.21.15, $RF3$ brightened, enlarged, and remained brilliant until it disappeared from the field of view because of a shift of the frame center. There was continual activity of small dark filaments near X; at 15.20.15, X brightened somewhat and did so abruptly at 15.20.45. We can consider the main flare to have begun at this time.

DODSON and HEDEMAN (1968) argue that the flare occurred simultaneously over two spot groups, beginning at $RF3$ in plage 8459, preceding the main group. On the other hand, we recognize the brightening around the main spot group to be the principle course of the flare, whereas the brightening at $RF3$ was never so extensive or intense as in plage 8461. Also, the brightening at X occurred 30 sec earlier. The flare wave, on the other hand, came from $RF3$, as we shall describe below.

3. The Main Flare

Following the brightening at point X between the two spots at 15.20.30, emission spread rapidly along L (away from the spot), starting at 15.22.00. At 15.24.51, several strands on either side of L brightened and elongated (Figure 3). The emission spread from the spots along L; but simultaneously brightening occurred at the far end of this line.

By 15.26.30, the two elongating strands reached their maximum length, and the growth of the flare changed, between 15.26.23 and 15.28.19, from an elongation to separation and broadening of the two strands (Figure 3). The average velocity of separation during the latter period was about 100 km/sec. After 15.28.30, the expansion became very slow.

The progress of the flare in plage 8459 was different. At 15.22.00, a region, $F3S$, at the base of the East end of filament $F3$ slowly brightened. At 15.26.00 (20 sec before the outward expansion of the main flare), a bright spray erupted from the base of the filament, moving southward (Figure 3). Unfortunately much of the spray was at the West end of our frame and disappeared behind the data panel; its velocity was about 1000 km/sec. The eruption occurred at the end of the spread of brightness along $F4$ and might have been a 'whip end' effect. There was a second pulse at 15.27.30, farther in the direction of filament $F4$ (i.e. SE).

The Sacramento Peak Observatory photographs show the flare wave at 15.28.45 (Figure 4) as concentric around the west end of $F3$, rather than the center of the flare. Thus the 15.26.00 eruption in plage 8459 was very likely the beginning of the flare wave. This would give a wave velocity around 1250 km/sec. The wave was also observed at the McMath-Hulbert Observatory (DODSON and HEDEMAN, 1968).

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The location of the source of the flare wave at the West end of the active region is similar to that of the wave of September 20, 1963, observed at Lockheed (ZIRIN and WERNER, 1966). It is of great importance that the disturbance producing these waves occurs on a neutral line under or near a spot filament. Many observations have been made (RAMSEY, 1967) of outflow along such filaments, which are an important channel by which energy leaves the spot group.

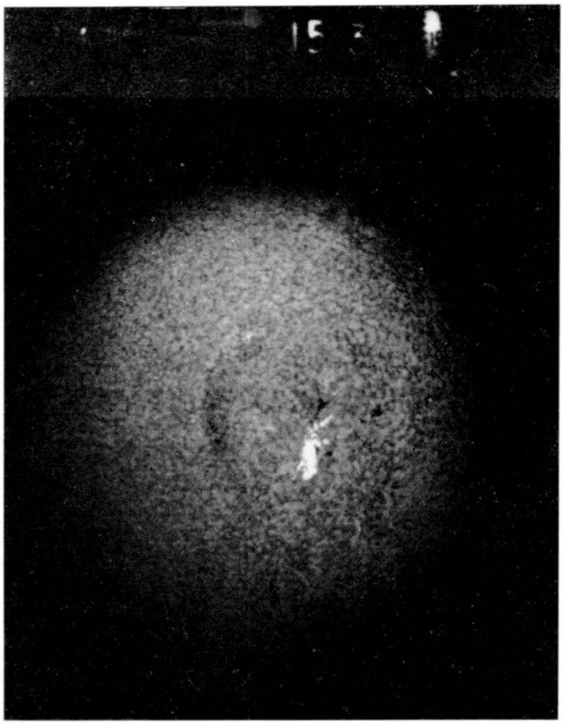

Fig. 4. Flare wave photographed at Sacramento Peak, 1/2 Å to the blue side of the line. (Courtesy of HYDER, 1968.)

At 15.31.45, another fast bright spray burst from a thin bright strand, *P*, outside the main flare area; it traversed 15000 km in 10 sec and disappeared off the edge of the frame.

After 15.28.30, the slow separation of the two strands of the main flare left behind an island of brightness in the center of a broad band of lower brightness (Figure 3). This band was crossed perpendicularly by many fine bright strands which probably were bright loop prominences; the 'island' may simply have been their bright tops. At 15.43.30, a feature (*R*) at the East end was certainly a bright loop prominence; it later became a dark loop prominence.

Sunspots play a significant role in the development of the flare. The beginning was clearly connected with the spot, *S*1; the first brightening occurred there, and grew in a circular path around it before spreading along the lane, *L*. The curve of the flare about the preceding sunspot is a common configuration; the flare of July 16, 1959 (DODSON and HEDEMAN, 1964), is an example. At 15.25.30, *S*1 was half covered and at 15.28.30, two-thirds of it was covered by the flare. By contrast, there was almost no flare brightening in the large complex spots that made up the Northern (and

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principal) part of the group. The Southward motion of spot $S1$ noted by McIntosh may be connected with the occurrence of the flare predominantly in the S part of the group.

The straight East-West line that marked the southern boundary (without penumbra) of these spots was the northern boundary of the flare. A similar phenomenon on September 16, 1963, is described by ZIRIN and WERNER (1966).

Although the outward expansion in the flash phase was about equal for both strands, the North strand stopped at 15.35.00 when it reached the polarity dividing line, while the South strand continued outward at 3.5 ± 0.7 km/sec. The inner edge of this strand moved at 4.2 ± 0.7 km/sec, so that it became thinner as it moved farther South. Although the outer edge of the North strand showed essentially no motion because it had stopped at the polarity boundary, its inner edge continued to expand at 4.2 ± 0.7 km/sec, and the strand rapidly narrowed. All velocities refer to the average of three points near the center of the flare.

It is well known that bright plages and flares are often limited by a sharp change in polarity. The absence of penumbra on the South side of the main spots indicates an extremely sharp boundary in this case. A comparison of the Hα and white-light pictures shows how the main flare strands followed the channel between groups of spots. It is remarkable that brightening never crossed between spots $S1$ and $S2$, but only curled around $S1$. The recurrences of this pattern in different flares point to an important connection with the energy-release mechanism.

The whole appearance of this flare in Hα is quite different from the numerous small flares that we have studied in detail. Rather than an eruption of brightness from a single source, as is typically observed in class-1 or -2 flares, energy was released almost simultaneously over a large region (in fact, over two spot groups). The flare began with activity in the main spots, but brightening occurred over the entire group. Since this flare is similar to other large ones, we may consider such behavior a characteristic difference between the activity of great as opposed to small flares.

This qualitative difference also appears in the energy production. Data given by FICHTEL and MCDONALD (1967) show that one great flare produces as many particles above 20 MeV as all the other flares of an entire year. This is undoubtedly connected with energy release over a large area.

The fact that the 'great flare' is quite different shows up in the preflare activity. While the normal small flare (class 1 or 1+) has few precursors, this one showed anticipatory activity 30 min earlier, particularly in the great filament eruption. The forces were at work all over the active region.

4. Correlation With Non-Optical Phenomena

The usual manifestations accompanying such a striking event were reported. The radio emission observed at Sagamore Hill was discussed in detail by CASTELLI and MICHAEL (1967), who observed a small burst in the band 8800–1415 MHz, starting at 14.46.50 with maximum at 15.01.50, probably connected with the precursor flare.

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An SFD reported by Fort Belvoir at 15.00.00 (see Table II) may also be part of the same event.

The main radio outburst was observed by many stations at many frequencies. Figure 5 shows the Ottawa 2800 MHz data; Figure 6 shows the data obtained and collected by the Heinrich Hertz Institute, which are similar to the Sagamore Hill observations. The centimeter burst occurred at the same time as the optical and X-ray events; a noise storm was detected at the long wavelengths. The maximum radio intensity was reached at 15.27.00 with a sharp fall off beginning at 15.30.00.

TABLE II

Ionospheric phenomena

Phenomenon and Importance	Wide ind.	Start	Max	End
SWF-SL 1 –	3	15.00	15.05	15.10
SFD 235	1	15.23	15.27	16.00
SEA 3	5	15.23	15.30	16.15
SPA 99	5	15.23	15.33	17.30
SWF-S 3 +	5	15.24	15.30	17.00
SES 2 +	5	15.26	15.30	17.20
SCNA 3	5	15.27	15.32	16.19
SFD 02		16.37	16.40	16.50

SWF-S: Sudden Short Wave Fadeout.
SWF-SL: Slow (Sic) Sudden Short Wave Fadeout.
SEA: Sudden Enhancement of Atmospherics.
SPA: Sudden Phase Anomalies at VLF.
SES: Sudden Enhancement Anomalies at VLF from 1 – to 3 +
SFD: Sudden Frequency Deviation.
Widespread Index 1 to 5: According to the number of stations which observed it.

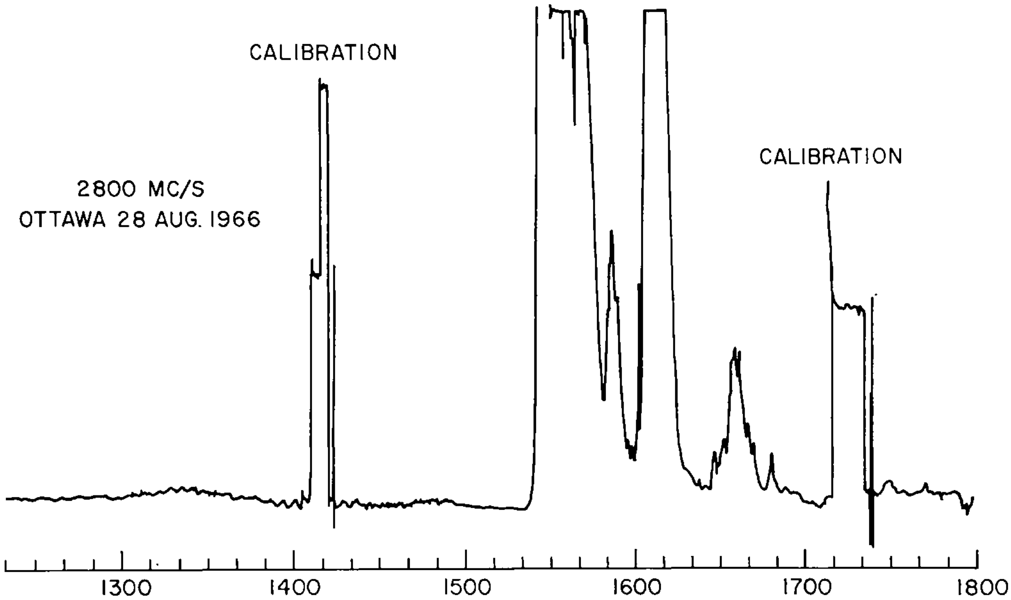

Fig. 5. Ottawa record of the burst at 2800 Mc/s. (Covington, 1967).

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We can conclude that the impulsive part of the microwave burst is well correlated with the flash phase in Hα as far as the end of the rapid separation of the two strands at 15.30.00. Using the observed area at 15.30.00, we find a brightness temperature of $T_B = 4 \times 10^8$ K.

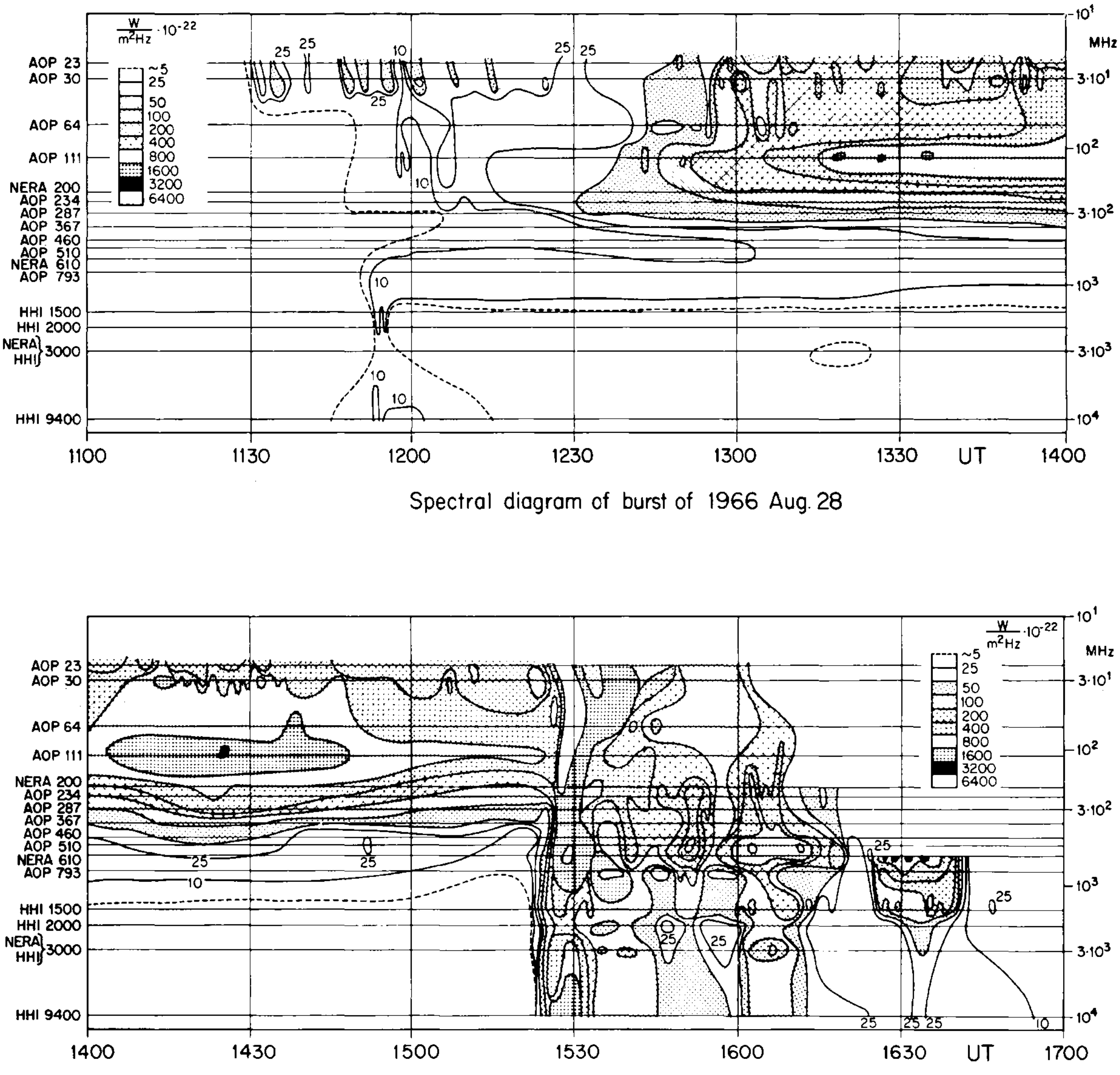

Fig. 6. Radiospectrum of the event (Supplement series of observational data of the Heinrich Hertz Institute). Report on the solar events of the period 1966, August 28–September 22, by Böhme and Krüger (1967).

There is a minimum in the radio flux around 2000 MHz. Below this frequency we have the Type II burst peak, produced by plasma oscillations in the corona; above it we have the microwave burst which is probably produced by synchrotron emission near the chromosphere. These are, of course, obscured by the corona at lower frequencies.

The high frequency records show a second peak of the emission at 16.05.00,

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which is evidently connected with the Type IV event at low frequencies. We find no counterpart in the Hα observations and therefore assume that the phenomenon was coronal.

The SCNA record from Boulder, corroborated by a similar one from Rome, shows that there were two ionizing pulses; the first, at 15.23.00, and the maindrop in signal at 15.29.00. The SCNA represents the integrated D-layer ionization, and is therefore difficult to connect with the exact flux.

The eruption of the filament before the flare does not correspond in time with either the radio bursts or the ionospheric events. The flare was followed by a proton event Fichtel and McDonald, 1967) with flux of 15 particles ($E>15$ MeV)/cm^2/sec/str), a PCA, and a geomagnetic storm, all of which are described in *Solar-Geophysical Data* (1966). On the other hand, relativistic electrons were not observed.

5. X-Rays

A large X-ray burst was recorded by a number of observers. The 2–12 Å Explorer 33 data of Van Allen and Krimigis (1966) are shown in Figure 7. A hard X-ray burst of energy greater than 80 keV (as well as soft X-rays) was recorded by Cline *et al.* (1968) with OGO 3. It was also observed in the 10–50 keV range (maximum sensitivity at 20 keV) by Arnoldy *et al.* (1968). There is a close connection between the expansion of the Hα flare and these bursts. Cline *et al.* observed the soft X-ray burst to increase above the detector background at 15.18.00, with a steep increase beginning at 15.20.00; Van Allen and Krimigis show a steep increase beginning at 15.22.00 ± 1. The increase peaked around 15.30.00. These times agree well with the spread of Hα brightness described in Section 3. The hard X-ray burst (>80 keV), on the other hand, began discontinuously at 15.25.30, peaked at 15.27.00, and decayed

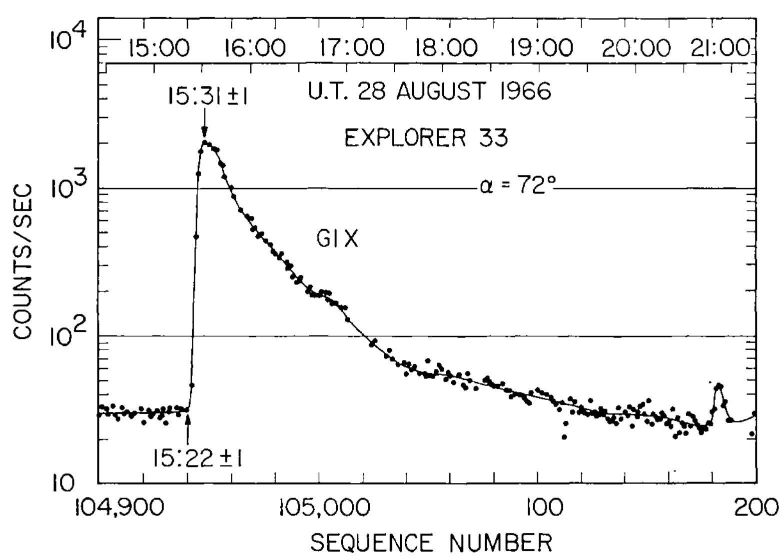

Fig. 7. Flux of X-rays, in the wavelength 2–12 Å measured from the Explorer 33 Satellite (Van Allen and Krimigis, 1966). By comparison, the hard X-ray burst began at 15.26.00, max 15.27.30, end 15.33.00.

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to zero by 15.33.00; the peak flux was about 180 photons/cm^2 sec. This agrees well with the period of rapid expansion of the two strands.

Since the flash period coincides exactly with the time of increase of the X-ray flux, we assume, for a model, that electrons were accelerated during this period and stored in a cylindrical volume overlying the region between the two strands. After 15.29.30, the volume increased slowly; presumably the X-ray emission fell off because the energy of the emitting plasma was radiated away.

Under these assumptions, we can calculate the densities required in the demi-cylinder to produce the observed X-ray flux, assuming that the temperature is similar to that recorded in other events. MANDEL'ŠTAM (1965) estimates that, at 3×10^6 K, the flux at the earth per unit density square and unit volume is

$$F/N_e^2 V = 1.57 \times 10^{-52} \text{ (c.g.s.)}, \tag{1}$$

in the range 2–12 Å. The volume at maximum in our case is 1.5×10^{28} cm^{-3}. For $F = 4.7 \times 10^{-2}$ ergs/cm^2 sec, we require N_e about 1.25×10^{11} cm^{-3} to explain the observed flux. If the temperature is 4000000°, we get about 1.4 times more radiation; thus the density might be reduced to 1.06×10^{11}. The density and temperature of this cloud are in rough agreement with previously published values (ZIRIN, 1964). If we assume that the principal energy loss comes from radiation in the 2–20 Å range, we can estimate the cooling time, from Mandel'štam's values, as $\sim 4 \times 10^3$ sec, in reasonable agreement with the observed lifetime of the 2–12 Å burst. Thus, the Van Allen and Krimigis soft X-ray data can be well explained by the creation of a hot coronal plasma in the flash phase of the flare. However, the impulsive rise suggests that there is some non-thermal flux at the start.

Although we can explain the soft X-rays with a reasonable coronal model, the hard X-rays present a more difficult problem. As pointed out by KORCHAK (1967) only bremsstrahlung can produce sufficient emission at this high energy. The bremsstrahlung formula is

$$J_\nu \, \mathrm{d}\nu = 5.44 \times 10^{-39} Z^2 g e^{-h\nu/kT} T^{-1/2} N_e N_i \mathrm{d}\nu . \tag{2}$$

In the case of July 7, 1966, CLINE *et al.* (1968) found $kT \approx h\nu$ for 80 keV; or $T \approx 10^9$. They inform us that the August 28 event was similar; in that case the total flux greater than 80 keV (200 photons/cm^2/sec) at the earth is produced by (taking $g \approx 1$, $Z \approx 1$):

$$F = 200 = \frac{5.44 \times 10^{-39}}{(AU)^2} \frac{T^{-1/2}}{h} e^{-1} N_e N_i V \text{photons/cm}^2\text{/sec} \tag{3}$$

$$= 0.427 \times 10^{-43} N_e N_i V. \tag{4}$$

Since N_i applies to ions of any energy, it may be as high as 10″; with $V = 1.5 \times 10^{28}$ cm^3, the density of 80 keV electrons may be as low as 2×10^5.

Cline *et al.* suggest that the electrons producing the X-rays also produce the microwave burst by synchrotron emission. We confirm this by applying Korchak's formula. The synchrotron emission for the energy spectrum $N(\gamma)\, \mathrm{d}\gamma = D(\gamma - 1)^{-5} \mathrm{d}\gamma$,

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(where $E=mc^2(\gamma-1)$) defined at $\gamma_0=80$ keV is:

$$P_s = 0.1 \frac{e^3 H}{mc^2} N_e (v/v_s)^{-1}, \tag{5}$$

where

$$v_s = v_{\text{gyro}}(\gamma_0 - 1) = 2.8 \times H \times 0.2\text{MHz} = 0.56\, H\, \text{MHz}, \tag{6}$$

H being the field in gauss. The flux at the earth at 10000 MHz is thus:

$$F = 5 \times 10^{-22} \frac{N_e V}{4\pi (AU)^2} \frac{H^2 0.56^2}{10^4} \text{erg/cm}^2/\text{sec}/Hz \tag{7}$$

$$= 3 \times 10^{-20} H^2 \text{w/m}^2/\text{Hz}.$$

So the observed microwave flux (1.6×10^{-19} w/m²/Hz) is produced for a field of 100 gauss or less. RAMATY and LINGENFELTER (1967) suggested that the long wavelength cutoff of the synchrotron radiation is due to the Razin effect in the corona. This may very well be so; however, if the electrons are at low levels, the cutoff may be due to simple absorption in the overlying corona; this is particularly likely in view of the high density overlying the active region; we can only see down to this low level at 3000 MHz.

Thus, once we accept the great number of 80 keV electrons needed to produce the hard X-ray burst, the suggestion of Cline *et al.* that these also produce the microwave burst by synchrotron emission can also be accepted. There is a slight time lag (1–2 min) between the X-ray and radio peaks in our case; it is difficult to tell if this is real or of any importance.

The fact that the hard X-ray peak precedes the soft X-ray peak by 4 min is sufficient to suggest that the $E > 80$ keV electrons are produced in limited volumes of the flare, perhaps in a single sheet or kernel. In that case, their density would be much higher, and they might well be thermal. The close time connection of the hard X-ray burst with the expanding strands may be more important.

6. Remarks on Flare Mechanisms

HYDER (1968) has discussed a model in which the erupting prominence produces the flare brightening as it falls back to the surface; he goes further to suggest that the erupting prominence material is thus accelerated to cosmic ray energies and produces the X-ray burst. This model uses a good explanation to explain too many things. While it is quite plausible that the maximum flare emission is produced by material raining down from bright loop prominences that condense out of the ejected material, all the primary motions in the flash phase of this and other flares are outward and impulsive. We have never seen an inward expanding flare. There is no way that we can conceive of the explosive phase as produced by a raining down of material. Further, the potential energy of the erupted material is only a few hundred volts per atom, just about the energy of the coronal cloud, and far less than the X-ray energies observed.

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It would appear more likely that a hydromagnetic instability begins at one point near the spots and spreads rapidly to all points of instability. The shock fronts produced by the growth of instability expel the filament, and could also produce particle acceleration at the leading edges. This would explain the close correlation between the explosive phase and the particle acceleration. If Hyder's picture were correct, we would expect considerable X-radiation and particle acceleration in the post-maximum period, when great quantities of material are obviously raining down on the surface. Instead, the X-ray flux always peaks at the end of the explosive phase. The exact nature of the hydromagnetic instability is speculative; we can only guess that the forces pushing the filament upward in the preflare period are connected with a great increase in chromospheric pressure contained by the arched horizontal field; eventually the material and field exchange places and the material erupts outward.

7. Subsequent Observations

Films of the same spot group were obtained by Zirin on the mornings of August 29 and 30 (Figures 8 and 9). Although the group was greatly changed on the 29th, it did not change further the next day. An interesting flare on the 30th is illustrated in Figure 9. The flare was a triple event, preceded by the upward motion of a prominence (14.22.00) which appears to be similar to that of the 28th. The flash phase at 14.51.00

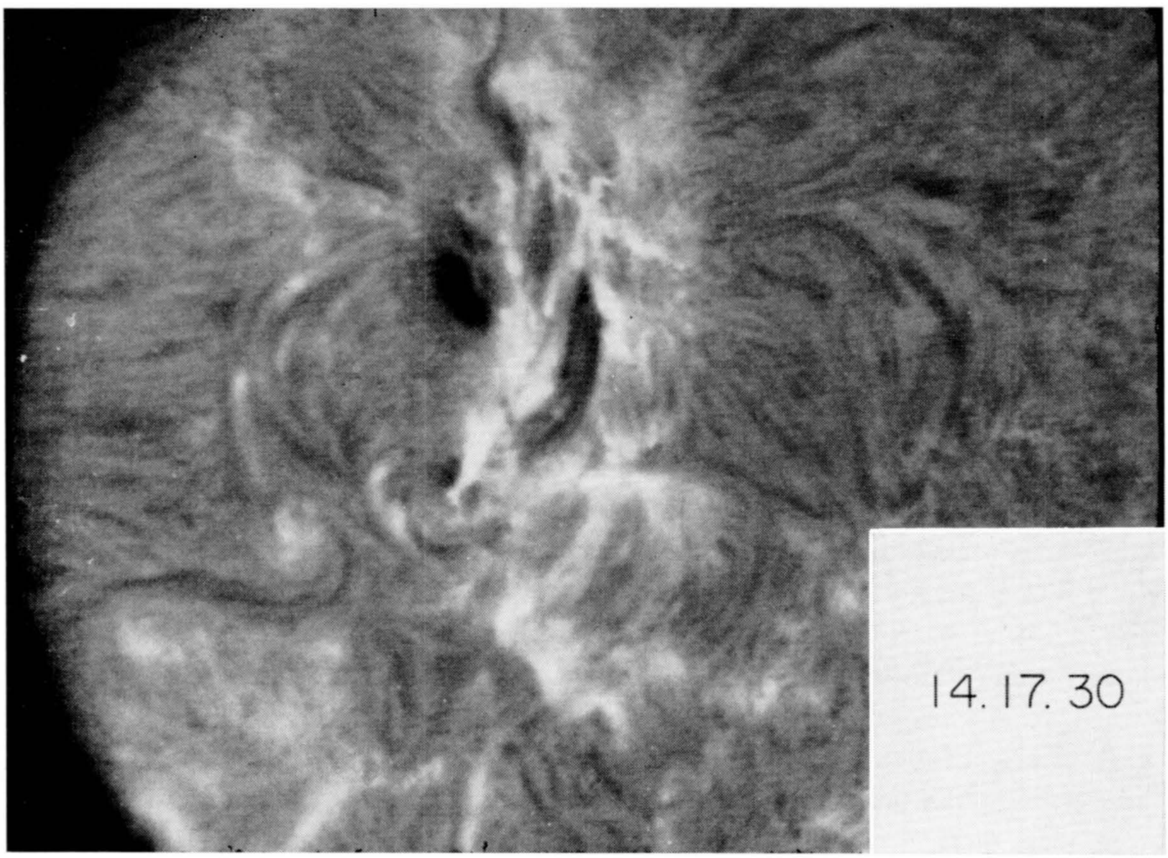

Fig. 8. Picture of the group August 29, 14.17.30. Note large change from August 28.

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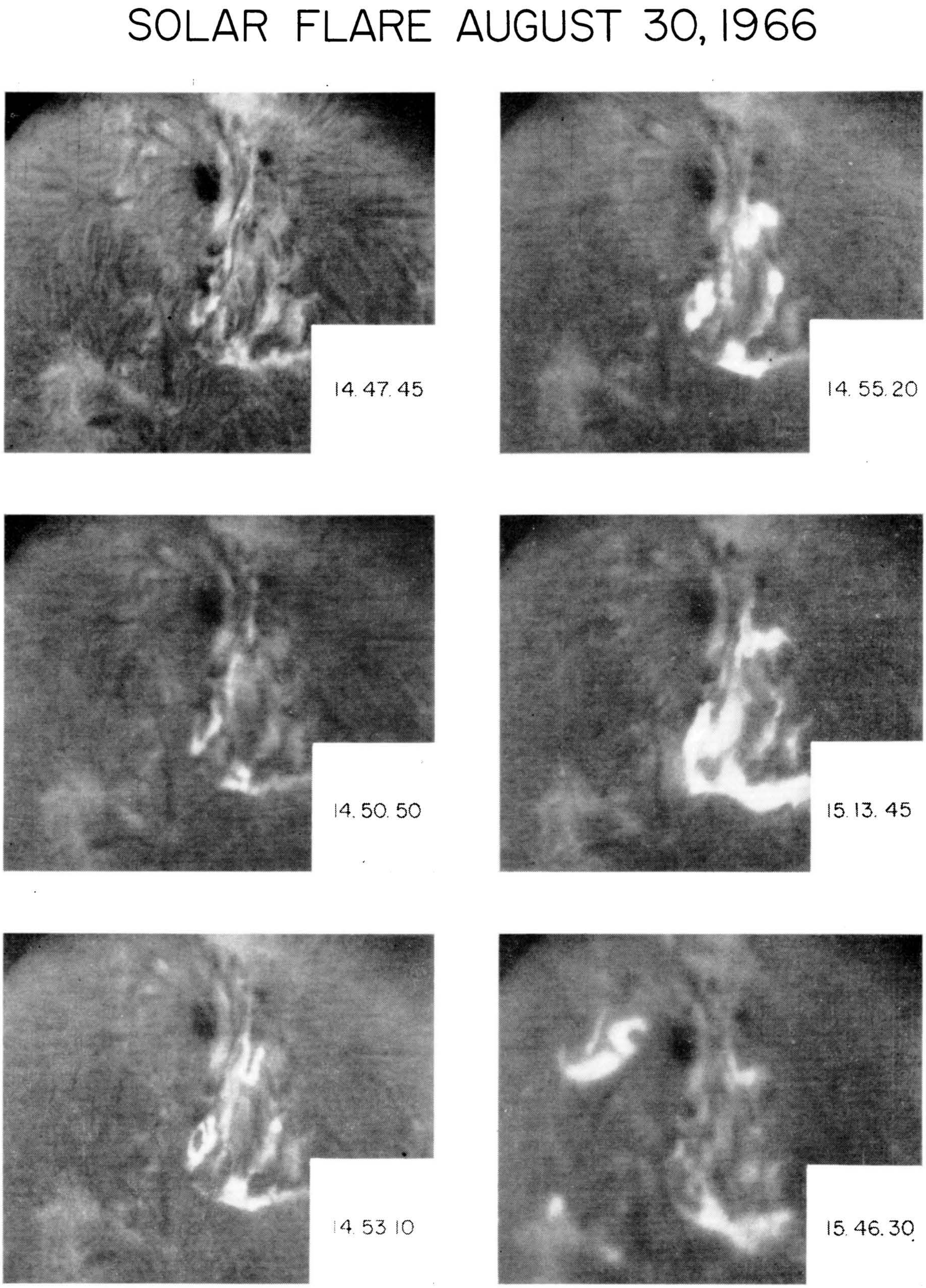

Fig. 9. Flare August 30, 1966. Note small change of general configuration from August 29.

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was simultaneous over a large area and accompanied by a centimeter burst and radio fadeout; the radio data reported in *Solar-Geophysical Data* (1966) show a peak flux around 1/6 that of the August 28 event. The second phase was an eruption for the North-West (lower left) corner of the flare at 15.11.00, as if the spreading energy release was focussed into an eruption at that point. This event was accompanied by small centimeter emission and an SFD (sudden frequency deviation). Finally, a new eruption, also accompanied by a centimeter burst and SFD occurred at 15.46.00 from the North edge of the big spot, spreading over a large curved trajectory. The first two events are certainly connected; the third may well be. It is interesting that the first flare shows no motion, only a sharp, widespread increase in brightness; yet it is the most energetic. This is normally the case; a discontinuous brightness increase is always more important energetically than a great physical eruption.

8. Summary

The August 28, 1966, flare is an excellent example of the growth of a large 2-strand flare, of the type responsible for the biggest particle events.

The stages of growth can be summarized as follows:

Preflare: (1) Precursor flare; (2) Filament eruption; (3) Beginning in penumbra of large spot; and (4) Rapid elongation of 2 strands on either side of the neutral line.

Flash phase: (5) Great spray and surface wave; (6) Rapid separation of strands, time of maximum brightness; and (7) Slow spread of brightness and subsequent decay.

It appears that energy is released from the entire area of the flare, although the starting point is at the big umbra. In this regard the great proton flare appears qualitatively as well as quantitatively different from small flares. In the latter we see an eruption of energy from a definite small area; in the former an initial impulse sets off a chain release of energy over a very large area. No doubt this effect is responsible for the tremendous increase in particle and radio emission from great flares, as compared to their area.

The spray and/or wave start some distance West of the main group, from under a large spot filament.

The X-ray data show that energetic particles are produced only during the flash phase. The X-ray emission in the declining phase is in reasonable agreement with simple decay by various cooling effects such as radiation and elastic collision of the coronal cloud. Although the soft X-ray component (2–12 Å) may be explained by a cloud of $N_e \approx 5 \times 10^{10}$, $T_e \approx 3 \times 10^6$; the hard component requires a kernel at a very high temperature (10^9 K) or a fraction (10^{-5}) of all the electrons at this energy. These electrons can produce the microwave burst by synchrotron emission.

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